DEVELOPMENT OF RENEWABLE ENERGY

RESOURCE SUPPLY CURVES

Phase 2: Renewable Energy Resource Assessment And Development Program

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SECTION 1. INTRODUCTION

RLA Consulting (RLA) has been retained by the State of Hawaii Department of Business, Economic Development, & Tourism (DBEDT) to conduct a Renewable Energy Resource Assessment and Development Program. This three-phase program is part of the Hawaii Energy Strategy (HES), which is a multi-faceted program intended to produce an integrated energy strategy for the State of Hawaii. This report summarizes the results of Phase 2 of the program, Development of Renewable Energy Resource Supply Curves.

PURPOSE

In Phase 1 of the program, suitable locations with development potential for renewable energy projects were identified and defined on each of the major Hawaiian islands. The emphasis for project identification was on utility-scale, grid-connected renewable energy projects. The purpose of Phase 2 is to develop resource supply curves based on the costs and performance of the potential projects identified in the first phase. The cost and performance estimates are based on current renewable energy conversion systems and realistic future projections with consideration of all the necessary components of a project, including financing, permitting, shipping, equipment integration, construction, operation, and maintenance. The results of Phase 2 include detailed cost and performance estimates for more than 230 potential renewable energy projects in the state as well as a user-friendly computer program that calculates the cost of energy for the projects and displays a graphical summary of the results of a specified query.

The information contained in this report is intended to summarize the baseline assumptions and present some illustrative results. The resource supply curve program was developed to provide the user with maximum flexibility to compare various options under differing conditions. As such, there is no single set of results. In addition, the objective of Phase 3 of the program is to concentrate on the integration and interpretation of the data. Therefore, limited conclusions have been drawn at this time. The final report for the project, completed in Phase 3, will include an integrated plan for incorporating renewables into the state's energy mix.

APPROACH TO DEVELOPING RESOURCE SUPPLY CURVES

In order to estimate costs and performance for renewable energy projects in Hawaii, RLA compiled the most current cost and performance data for each of the renewable energy conversion technologies to be evaluated in the project. Technologies included wind, solar thermal (trough and dishes), photovoltaics (fixed and tracking arrays), biomass electricity (including municipal solid waste), biomass fuel (both ethanol and methanol), hydroelectric, wave, and ocean thermal. For each potential project, costs and performance were estimated based on site-specific resource data and other information, then technology data worksheets were developed to summarize the detailed information for the project in an accurate and consistent manner.

A Resource Supply Curve (RSC) computer model was then developed to calculate the levelized cost of energy for each project based on the Electric Power Research Institute Technical Assessment Guide (EPRI TAG) methodology, a common set of economic parameters, and the data provided on the technology data worksheets. The results of the program are a graphical presentation of the cost of energy of each project versus the cumulative energy for all the projects meeting a specified criteria.

Resource supply curves provide a means for comparing costs of different projects within a specific technology and between technologies for each island or for the state as a whole. They can be used to determine which technologies can make the greatest energy contribution on a given island and to the state as a whole considering both the availability of the resource and the technology's economics. The primary value of resource supply curves is in comparing different generating options with each other given similar economic assumptions and evaluation methodologies. Because of changing economic conditions, financing assumptions, tax credit considerations, and costing methodologies, the values generated by the RSC program should not be used as absolute values outside the context of the program (i.e., for contracting purposes or pricing justification). Similarly, the values should not be compared against other non-renewable generating options unless the cost of energy is calculated using a consistent approach and methodology.

REPORT ORGANIZATION

This report is organized into three main sections. Following the introduction, Section 2 summarizes the approach and assumptions used to estimate the costs and performance for each of the potential renewable energy projects evaluated. Section 3 discusses the economic basis for calculating the cost of energy and contains illustrative results and examples from the RSC program. The technology data worksheets, guidelines for using the RSC computer model, and illustrative results for each island and technology are included in appendices.

SECTION 2. COST AND PERFORMANCE ESTIMATES

In developing cost and performance estimates for each of the projects evaluated in this program, RLA combined state-of-the-art knowledge regarding the status of the technology and its future implementation with a practical perspective on the elements necessary to bring a project from its conception stage to successful operation in Hawaii. The results are realistic estimates bounded by optimistic and conservative ranges to represent the uncertainty associated with the technology development or the resource availability.

OVERALL APPROACH

For each potential project location identified in Phase 1 of the Renewable Energy Assessment and Development Program, a number of possible project sizes were evaluated. The size and number of projects evaluated at each location was based on several factors. The size and characteristics of the land parcel available for potential development was the primary consideration. In some cases, only one project size was evaluated because land constraints prohibited consideration of other sizes. In most cases, however, multiple project sizes were evaluated because sufficient land was available to support larger projects.

The capacity of the existing transmission lines was the next criteria used to define potential project sizes. For most locations, transmission upgrades were required for projects above a certain size. In these cases, the largest project that could be installed at a particular site without costly transmission upgrades was evaluated. Larger projects (which included the costs of transmission upgrades) were also evaluated as appropriate.

The size of the utility grid on each island was also a consideration. For islands other than Oahu, projects larger than 30 MW may be difficult to develop because of the size of the existing utility grid and the projected demand growth. As a result, 30 MW project sizes were evaluated for sites in which other constraints did not define the size. On Oahu and for a few cases on the other islands, projects of 50 MW or larger were evaluated. This is justified on Oahu because of the size of the utility grid. Large projects were evaluated on the other islands to provide additional data on the economies of scale, and to account for any future changes in demand due to factors such as island interconnection, large load growth, or load profile changes.

For most technologies, two conceptual plant designs were developed. One design was based on plant components that are commercially available for installation in 1995 projects (current technology). The other design was based on components that are realistically expected to be commercially deployed by the year 2005 (future technology). In the case of technologies that have not been commercially deployed, estimates were made for only the future scenario. For mature technologies in which no substantial technological advances are expected, estimates were developed for only the current scenario.

In order to account for the uncertainty in cost and resource projections, three estimates (representing optimistic, nominal, and conservative cases) were made for each potential project and for both stages of technology development (current or future). As a result, a total of six cost and energy estimates were made for each potential project location and size for the majority of the technologies evaluated.

The optimistic, nominal, and conservative cases differ from each other because of uncertainty in energy production, project costs, or a combination of both. Energy production estimates vary to reflect the uncertainty of the resource, as well as the potential variation in energy conversion efficiency of the technology. Cost estimates vary to reflect uncertainties in factors such as the development pace of the technology, changes in market conditions, variations between suppliers and developers, and other uncertainties inherent in estimating project costs in an environment where few projects of this type have been completed. The nominal value represents the best estimate but is not necessarily the mean value of the range.

Project performance estimates are based on the conceptual plant designs, potential project sizes, and the best available resource data. For wind and solar projects, additional data collection is underway at a number of the sites. Performance estimates for these technologies will be updated when better resource data are available and the results will be included in the Phase 3 report. In all cases, gross energy estimates were calculated and energy losses were assumed to account for factors such as line losses and downtime. The net energy estimates are the amount of energy expected to be delivered to the utility grid.

Costs on the technology data worksheets are estimated in a manner that is consistent with the EPRI TAG method of evaluating utility generating alternatives and are stated in 1995 dollars. Only the total capital costs, the total annual expenses, and the net annual energy production are used in the resource supply curve model. The detailed itemization of costs is given on the worksheets to provide supporting documentation for the totals, allow comparison between different projects, and ensure consistency. A description of the cost components follows.

Capital Costs include Total Plant Costs and Initial Costs. Total Plant Costs are made up of five components: process capital, general facilities capital, engineering and overhead, project contingency, and process contingency. Each of the components of the Total Plant Costs and Initial Costs is discussed in more detail below:

> *Process Capital* is the total constructed cost of all on-site processing and generating units, including all direct and indirect construction costs. The estimates have been made based on site layouts consistent with the geographic and topographic constraints at each project location. Storage facilities and equipment required for fuel delivery and waste removal (if any) are included. Major equipment costs are based on recent equipment purchases whenever possible, and other equipment costs have been scaled based on costs from similar facilities. Labor costs were estimated from comparison with similar projects and have been adjusted to account for site constraints and local labor rates.
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> *General Facilities Capital* includes the cost of such facilities as roads, office buildings, shops, etc., that are required for plant operations, but which do not necessarily directly contribute to the production of the energy end product.
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> *Engineering and Overhead* is assumed to be 10% of the process capital.
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> *Project Contingency* is assumed to be 10% of the sum of the above three categories. Project contingency is meant to cover the cost of additional equipment or unexpected costs that may be overlooked in a preliminary cost estimate.
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> *Process Contingency* is defined in the EPRI TAG as a capital cost contingency factor applied to a new technology in an effort to quantify the uncertainty in the technical performance and cost of the commercial-scale equipment. In this study, process contingency is accounted for by the variation between the conservative and optimistic estimates of cost and performance. As such, no additional amount for process contingency has been added to the cost estimates.

Initial Costs reflect the cost of supplies needed on hand to begin operating the power plant. Initial or start-up costs include the equivalent of one month's operating costs, 25% of one month's fuel cost (if applicable), 2% of the Total Plant Cost (a simplifying assumption from the EPRI TAG) to account for any last minute changes, and the capital required for inventory of spare parts, fuel on hand, or other miscellaneous expenses.

Annual Expenses include the annual costs associated with project operation which are divided into two basic categories: fixed and variable. Variable costs are directly associated with how much energy is produced, while fixed costs are unaffected by the energy production. The annual operating costs include an allotment for periodic component replacements levelized on an annual basis.

Due to the high value of land in Hawaii, it is most likely that land for any potential renewable energy project will be leased rather than purchased. Land lease costs are included as a fixed operating cost. Lease rates depend on the land's value for other uses and the land owner. For consistency purposes, land lease costs were estimated for different categories of land ownership including private, state, federal (military), and Hawaiian Homes land, and these values were applied consistently among projects.

In order to adjust U.S. mainland costs to Hawaii, cost indexes were applied based on the R.S. Means Building Construction Cost Data, 1993.[1] This document specifies indexes for materials and installation of various construction-related projects for use in adjusting costs between U.S. cities. Additional cost information on labor rates, equipment rental, and construction processes was obtained from construction companies involved with projects on each of the Hawaiian islands and this information was applied as appropriate.

Permitting costs were estimated based on discussions with county, state, and federal permitting offices in Hawaii and they vary based on the technology type and the zoning classification of the project site. Shipping costs are based on recent quotations and actual equipment weight and include delivery of the equipment to the project site.

Transmission costs were based on discussions with Hawaiian Electric Company, recent studies of transmission upgrades, and costs for other utilities adjusted to Hawaii conditions.

TECHNOLOGY-SPECIFIC ASSUMPTIONS

The following sections describe the assumptions that were made for each of the renewable energy technologies evaluated in this study. For each technology, the technology status, performance assumptions, and cost basis are outlined.

WIND

Technology Status: Wind energy is a technology that has been commercially deployed on a large-scale basis for more than ten years. However, technology advances continue to improve the performance and reliability as well as reduce the cost of the technology. Research through the U.S. Department of Energy (U.S. DOE), European Community, and others is aimed at numerous technological advances to further reduce the cost of energy from wind projects. For this study, current cost and performance estimates are meant to reflect wind technology that is currently being bid for projects that will be installed in the 1995 time frame.

[1] Means Building Construction Cost Data, 50th Edition, R.S. Means Company, Inc., 1991.

Future cost and performance estimates were scaled from current estimates based on technology advances that are currently under development and expected to be achievable in the next ten years. These developments include: improved aerodynamic performance, increased rotor size, higher installed capacity per turbine, advances in variable-speed technology, improved controls, and the cost advantages associated with mass production. Some improvements are also incorporated to account for increased industry experience that will reflect the incremental lessons learned in project construction, management, and operations and maintenance.

Performance Assumptions: Estimates of the wind resource at specific sites were based on historical data in the vicinity of the site, new data being collected under the Renewable Energy Resource Assessment and Development Program, and RLA's judgment. The variations between optimistic, nominal, and conservative performance estimates account for uncertainty in the resource data. A power curve for a hypothetical wind turbine was used to estimate per-turbine production at each site. In addition, the following assumptions were made:

- Hourly wind resource data were used for each site where high-quality data were available. In the absence of actual hourly data, site wind speed distributions were determined based on a Weibull distribution (k = 2.9) and estimated average annual wind speeds. The shape of the Weibull distribution was matched to the shape of distributions from typical Hawaii sites for which high-quality data were available. The average annual wind speeds were estimated based on the nearest available data and results from the on-going monitoring program.

- Estimated energy losses were determined on a site-specific basis and range from 18%-28%, depending on the site conditions and potential project layouts (particularly the spacing between turbines). Energy losses account for blade soiling, array effects, control inefficiencies, turbulence, downtime, and line losses.

- A hypothetical wind turbine representative of commercially available technology was used for project layout purposes. It was assumed that the turbine had a 30 meter rotor diameter and was mounted on a 120 foot tower.

Cost Basis: Itemized costs were developed for each nominal current technology case using the best currently available information. Future costs were estimated based on projections by U.S. DOE, EPRI, and others. The following assumptions were made:

- Equipment costs are based on publicly available information from equipment manufacturers and recent bids for actual projects. Balance-of-station costs are based on installation information on operating projects in California, adjusted to account for costs in Hawaii and expressed in terms of 1995 dollars.

- Parametric costs were developed for construction based on three different soil types: lava, rocky, and dirt.

- Parametric costs were developed for balance-of-station costs and construction costs based on types of terrain to account for larger spacing between turbines and ease of construction.

- The size of the control buildings, monitoring systems, and support equipment varied by project size.

- Turbine and tower costs were varied to reflect larger production run discounts. A discount was applied to the equipment costs for projects larger than 50 MW and a surcharge was added to projects 5 MW or smaller.

- The majority of balance-of-station costs are assumed to be proportional to the number of wind turbines in the project. Costs for roads, grading, and electrical interconnection are scaled according to the ruggedness of the terrain and the soil type.

- Land and permitting costs vary according to land ownership and zoning.

PHOTOVOLTAICS

Technology Status: Although a large market exists for photovoltaics for remote power applications and consumer products, there is limited experience with large-scale photovoltaic installations for bulk electricity generation. However, there are multiple demonstration projects installed throughout the U.S., including a PVUSA (Photovoltaics for Utility Scale Applications) satellite project located near Kihei on the island of Maui. For this study, current cost and performance estimates are based on experience with recent demonstration projects. Research is concentrated on increasing module efficiency and improving manufacturing processes. Future costs and performance estimates are scaled from current technology values based on industry estimates of improved efficiency and the cost advantages associated with mass production.

Performance Assumptions: Typical Meteorological Year (TMY) weather data from Barber's Point, Oahu, serves as the basis for the annual energy production estimates. TMY data are a compilation of "typical" climatic months selected from a 23 year database. The data are in hourly format and designed to provide an accurate portrayal of the long-term average climatic regime. The weather data consist of direct normal beam irradiance, global horizontal irradiance, ambient dry bulb temperature, and wind speed. Indices were used to extrapolate the results from Barber's Point to other project sites in Hawaii. The indices were based on historical climatic data in the vicinity of the site,[2] new data being collected under the Renewable Energy Resource Assessment and Development Program, and engineering judgment. The variations between optimistic, nominal, and conservative performance estimates account for uncertainty in the resource data. In addition, the following assumptions were made:

- Both fixed and tracking photovoltaic systems were evaluated. Fixed systems were assumed to face due south at a 15 degree tilt angle. For tracking systems, a north-south, single-axis tracking array structure was assumed.

- Current technology assumes a 13.5% efficient crystalline module at 1000 W/m^2 and 20°C.

- Future technology assumes a 17% efficient crystalline module at 1000 W/m^2 and 20°C.

- A ground cover ratio of 70% was assumed.

- Energy losses are assumed to be approximately 16%, which includes consideration of inter-array shading, cabling losses, and power conditioning efficiency.

[2] Kearney, D. *Solar Electric Generating System (SEGS) Assessment for Hawaii*, State of Hawaii Department of Business, Economic Development & Tourism, Honolulu, Hawaii, December 1992.

- The array field layouts are designed to minimize wiring and associated power losses, and the array field layout is optimized on the basis of inter-array shading.

Cost Basis: The following cost assumptions were made:

- Equipment costs are based on recent information from equipment manufacturers and experience with demonstration projects.
- Parametric costs were developed for foundations and construction based on three different soil types: lava, rocky, and dirt.
- The array structure costs are based on designs used extensively in recent utility PV installations.
- Module costs vary to reflect production run discounts. In addition, future module costs are reduced to represent mass production cost advantages due to a larger market for PV systems.
- For future technology, infrastructure costs were reduced due to the increased efficiency of the modules (fewer modules are necessary for the same size project).
- Land and permitting costs vary according to land ownership and zoning.

SOLAR THERMAL

Technology Status: Three main types of collectors have been used for solar thermal systems: parabolic troughs, parabolic dishes, and central receivers. Central receivers were not evaluated in this study because of land use constraints in Hawaii and the status of the technology. Parabolic trough systems are the most mature solar thermal technology and they have been extensively deployed in commercial projects in California. Prototype parabolic dish systems have been operated on a limited basis. However, extensive research and development has resulted in continuing component improvements and expected cost reductions. Current technology cost and performance information for solar trough systems is based on experience with recently installed commercial projects. Current technology cost and performance information for solar dish systems is based on projections for Dish-Sterling systems currently under development and expected to be commercially available in 1995-97. Future technology estimates are scaled from the current estimates based on knowledge of technological advances that are currently under development and expected to be achievable in the next ten years.

Performance Assumptions: Typical Meteorological Year (TMY) weather data from Barber's Point, Oahu, serves as the basis for the annual energy production estimates. TMY data are a compilation of "typical" climatic months selected from a 23 year database. The data are in hourly format and designed to provide an accurate portrayal of the long-term average climatic regime. The weather data consist of direct normal beam irradiance, global horizontal irradiance, ambient dry bulb temperature, and wind speed. Indices were used to extrapolate the results from Barber's Point to other project sites in Hawaii. The indices were based on historical climatic data in the vicinity of the site,[3] new data being collected under the Renewable Energy Resource Assessment and Development Program, and engineering judgment. The variations between optimistic, nominal, and conservative performance estimates account for uncertainty in the resource data. In addition, the following assumptions were made:

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[3] Kearney, D. *Solar Electric Generating System (SEGS) Assessment for Hawaii*, State of Hawaii Department of Business, Economic Development & Tourism, Honolulu, Hawaii, December 1992.

- Performance of solar trough systems is based on the operation of the Solar Electric Generating Station (SEGS) plants in California. Future performance for trough systems is based on industry projections and engineering judgment of factors such as expected solar field improvements.

- Performance of the solar dishes is based on prototype testing results and performance models. Future performance is increased by approximately 5% to account for increased efficiency.

- For solar dishes, utility-scale units of 25 kW are assumed.

- For solar troughs, north-south, single-axis tracking is assumed.

Cost Basis: The following cost assumptions were made:

- Equipment costs for the solar trough systems are based on data from the SEGS plants in California and recent quotes on major equipment from vendors.

- Cost assumptions for the solar dish systems are based on research conducted for the U.S. DOE by SAIC. Future costs are estimated based on knowledge of research and development programs, both within the U.S. and abroad.

- Parametric costs were developed for foundations and construction based on three different soil types: lava, rocky, and dirt.

- For solar dishes, future cost estimates are reduced to represent cost advantages due to higher production rates because of an anticipated larger market.

- Land and permitting costs vary according to land ownership and zoning.

HYDROELECTRIC

Technology Status: Hydroelectric is a mature technology. There are few appreciable differences between the types of projects that would be installed in 1995 and those that would be installed in the year 2005. As a result, only current technology projects are evaluated in this study. New projects are expected to have lower operation and maintenance costs than existing projects resulting from semi-automatic operating strategies and improvements in designs.

Completing the permitting and environmental requirements of hydro projects in Hawaii has proven to be difficult due to the high value placed on natural resources and competing uses. For these reasons, and due to the porosity of the ground soil, hydroelectric projects developed in Hawaii are likely to be run-of-the-river rather than storage type projects.

Performance Assumptions: A computer simulation model was used to predict hydroelectric performance based on series resource data, head, pipe sizes, and turbine type. The model accounts for frictional losses in the penstock, operational restrictions, and turbine/generator efficiencies. Water resource data were based on either information from actual project proposals or hydrology reports completed for nearby hydroelectric facilities. Information on rainfall estimates and soil characteristics was also examined. Allowances were made for water bypass to maintain minimum streamflows to maintain river ecology. Energy losses account for power transformation and transmission to the utility grid.

Cost Basis: Cost estimates are based on recent experience with hydroelectric project development both within Hawaii and at other mainland locations.

BIOMASS

Technology Status: There are a number of methods for converting biomass to energy. In this study, both the conversion of biomass to electricity and the conversion of biomass to liquid fuel (both ethanol and methanol) were evaluated. Biomass fuel sources include energy crops of either trees, grass crops and organic waste (agricultural and/or municipal solid waste). The biomass conversion technologies selected for evaluation in this study are based on the their applicability to Hawaii's feedstocks and conditions.

There is extensive experience in Hawaii converting biomass to electricity. Current biomass-to-electricity technology is relatively mature. Biomass-to-electricity projects utilizing bagasse and organic waste as a fuel source are currently in operation in Hawaii. These projects use a biomass-fired boiler to drive a steam turbine/generator with either tree crops, sugar, or organic waste as a fuel source. This conversion process was used as current technology for this study.

Future projects converting biomass to electricity are likely to use biomass fixed bed gassifiers integrated with open cycle gas turbines[4] and this type of conversion technology was assumed for the future biomass-to-electricity projects evaluated in this study. Examples of gassification technology are currently being demonstrated.

For biomass-to-liquid-fuel projects, only future conversion technologies were evaluated. The process of converting some types of biomass to ethanol is commercially developed in parts of the world. The conversion of corn to ethanol is currently practiced on the U.S. mainland and sugar cane is converted to ethanol in Brazil; however, these technologies are not considered to currently be commercially viable in the Hawaiian environment. Future biomass-to-ethanol projects will incorporate advanced techniques such as acid pre-treatment, simultaneous saccharification and fermentation, distillation, and co-product utilization.

The production of methanol from biomass is another possible future technology. While this process is not yet commercially available, technology is being developed that will produce methanol from biomass through a process of biomass gassification coupled with conditioning and catalytic reactions.

Performance Assumptions: Biomass crop yields were estimated using the Hawaii Natural Resources Information System database and data from the Hawaiian Sugar Planters' Association. Estimates of the annual generation of organic waste material were obtained from a recent survey of Hawaii's organic waste potential that was completed for DBEDT by Unisyn.[5] Additional assumptions include:

- Feedstock supplies were calculated for plant sizes at 25 MW or 25 MGPY (million gallons per year) and 50 MW or 50 MGPY.

- The production of tree and grass crops at the same site were mutually exclusive because the same land area would be required for either crop. Combinations of either tree or grass and organic waste, however, are possible and are used to achieve the minimal amount of feedstock for the two targeted plant capacities.

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[4] California Energy Commission. *1992 Energy Technology Status Report*, 1992.
[5] Unisyn Biowaste Technology. *Feasibility Study of Organic Waste Conversion Facilities in Hawaii, Draft Report*, prepared for the Department of Business, Economic Development & Tourism, 1993.

- A 7 year growth cycle is assumed for tree crops based on experience and research on short-rotation tree crops in Hawaiian conditions. The land parcels with the highest tree yields were utilized first to meet the feedstock requirements.

Cost Basis: Cost estimates for biomass installations were based on the results of recent studies. Assumptions include:

- Plantations are assumed to be located on existing agricultural lands planted in crops. Conversion facilities are assumed to be located at the site of existing conversion or processing facilities because the usable agricultural lands currently have existing facilities associated with them.

- Site preparation, planting, and harvesting are assumed to be conducted continuously.

- Existing main and access roads are usable for biomass purposes and therefore no additional costs were included. New feeder roads were assumed as required.

- Costs associated with seeding and planting, fertilizer applications, mowing, etc., are based on current practices and experience in Hawaii.

- Land and permitting costs vary according to land ownership and zoning. Land lease fees for agricultural land are based on existing practices.

- A revenue stream resulting from tipping fees for organic waste disposal is assumed for facilities using municipal solid waste. Actual tipping fees or those proposed in recent solid waste management plans are used for Maui, Kauai, and Hawaii ($17.00, $19.50, $17.00 per fresh ton, respectively). On Oahu, a tipping fee of $25.00 per fresh ton is assumed. Although higher tipping fees are currently in effect on Oahu (approximately $54.00 per fresh ton), this level of payment is due largely to the costs associated with the operation and payment of debt on the incinerator/RDF system (H-POWER).

- The cost of energy for biomass fuel projects was converted into cents/kWh to allow for comparison to electricity generating biomass projects.

WAVE

Technology Status: There are a number of different wave energy conversion devices currently under development. For this study, a heaving buoy, hose pump system was assumed based on its economic benefits when compared with other wave energy conversion systems.[6] Because this technology is currently in the demonstration stage, only future technology projects were evaluated.

The reference design consists of one or more star-shaped clusters of buoys, moored in an 80 m water depth. Each star contains 60 buoys and six collecting lines arranged symmetrically around an underwater habitat, which houses a 10 MW turbine generator.

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[6] Hagerman, G. and F.P. Heller. "Wave Energy: A Survey of Twelve Near-Term Technologies," *Proceedings of the International Renewable Energy Conference*, Honolulu, Hawaii, September 1988, pp. 98-110.
Hagerman, G. "Wave Power," *Encyclopedia of Energy Technology and the Environment*, edited by A. Bisio and S.G. Boots, New York: John Wiley & Sons, Inc., 1994 (in press).

Performance Assumptions: The resource data used to estimate the performance of potential wave energy projects are based on a review of the available statistical summaries of visual, hindcast, and measured wave data in Hawaii. The performance was based on the best fit of the projected absorption efficiency of buoy/pump modules in random waves to the results of different numerical model simulations. The variation between optimistic, nominal, and conservative estimates accounts for the variation in the model results. The following assumptions were made:

- The conversion of absorbed power to offshore electric power assumed 90% fluid power transfer efficiency from the buoys to the underwater habitat and 90% turbine generator efficiency.

- Line losses vary with assumed line sizes and sea-to-shore distance. Sea-to-shore distances vary from 1.5 km to 8 km, depending on location.

Cost Basis: Costs are based on conceptual designs developed for a 30 MW facility off the northern California coast, adjusted to account for costs in Hawaii. The following cost assumptions were made:

- Equipment costs are based on quotes from component suppliers and lease rates for an onshore fabrication yard and offshore deployment equipment.

- A 30% contingency for weather delays was applied to all offshore equipment mobilization and deployment activities.

- Operation and maintenance costs were based on experience with offshore tanker terminals.[7]

[7] SEASUN Power Systems. *Wave Energy Resource and Economic Assessment for the State of Hawaii*. Energy Division of the State of Hawaii, Department of Business, Economic Development & Tourism, 1992.

OCEAN THERMAL ENERGY CONVERSION (OTEC)

Technology Status: Hawaii has been a leader in the research and development of ocean thermal energy conversion technology. For this study, the basic conceptual design was assumed to be a land-based, closed-cycle, ammonia power system plant. Because this technology is currently in the demonstration stage, only future technology projects were evaluated in this study. Cost and performance data are based on research conducted and published by PICHTR in cooperation with U.S. DOE and work conducted in the mid-80s on the DOE OTEC Pilot Plant Program.

Performance Assumptions: The ocean thermal resource is based on the bathymetry, which is a measurement of the depth of water in the ocean, and by the seasonal surface temperature variations. The following performance assumptions were made:

- The conversion efficiency, availability, and parasitic losses were based on research projections and were varied among the optimistic, nominal, and conservative cases to account for uncertainty in the technology.

- At Kahe Point, performance was assumed to be enhanced by the warm water discharged from HECO's onshore thermal power plant at that site.

Cost Basis: All cost estimates for the conservative cases were based on the detailed work breakdown structure and associated cost estimate prepared by Ocean Thermal Corporation and its subcontractors, adjusted to 1995 dollars.[8] All costs estimates for the nominal and optimistic cases are derived from more recent work conducted by PICHTR.[9] Adjustments to these costs were made as appropriate in order to ensure consistency in approach and costing methodology for this study.

GEOTHERMAL

Technology Status: Geothermal energy conversion from high-temperature (>150°C) water dominated resource areas is a mature technology that has been commercially deployed since the 1960s. While research and development efforts are underway for advanced technology applications such as energy conversion from magma, these advances are not expected to be commercially viable by the year 2005. Such developing technologies are not considered in this study.

Cost and performance estimates in this study reflect conventional flash-plant technology. One such geothermal facility is currently operating on the Big Island in the Kilauea east rift zone. The potential geothermal projects included in this report represent additional 25 and 50 MW generation capacity installed near the existing facility. However, due to recent experience with public opposition to geothermal development in this area, it is expected that new geothermal development would require a lengthy permitting process before drilling and/or construction could be initiated. Therefore, the geothermal projects are presented as future technology (able to be installed by 2005).

Performance Assumptions: The Kilauea east rift zone is known to be a high-temperature hydrothermal resource area. This fact has been confirmed by recent assessment and project development activities.

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[8] Carmichael, A.D., E.E. Adams, and M.A. Glucksman. *Ocean Energy Technologies: The State of the Art*, Electric Power Research Institute, Palo Alto, California, EPRI AP-4921, 1986.

[9] Vega, L.A. " Economics of Ocean Thermal Energy Conversion (OTEC), in *Ocean Energy Recovery: The State of the Art*, edited by R.J. Seymour, American Society of Mechanical Engineers, New York, New York, 1992, pp. 152-181.

Performance estimate variations for conservative, nominal and optimistic cases accounts for the normal differences that are encountered between different production wells both in resource temperature and flow rate. Other factors that affect a plant's productivity are the efficiency losses associated with corrosivity, scaling, and equipment required to account for gas concentrations. The following basic assumptions were made:

- The resource is a high temperature water dominated area. A normal amount of site and well variation is assumed relative to the experience of the existing power plant location.
- The exact plant configuration would depend on the resource condition, but is almost certain to include flashing, condensation, and reinjection.
- Energy losses include transmission losses, parasitic losses such as pumping, downtime, and equipment fouling.

Cost Basis: The following cost assumptions were made:

- Construction costs were based on the typical costs associated with similarly sized geothermal projects adjusted to account for Hawaii specific cost factors. The estimates assume that project construction management is handled appropriately to avoid any unnecessary overruns.
- Drilling costs include the assumption that some of the wells drilled will be non-productive. Even with the exploration performed for the existing facility, non-productive wells can be expected for any future expansions.
- Variations in the power plant costs account for potential variations in resource temperature, gas concentrations, corrosivity, and scaling characteristics.
- Permitting cost assumptions are consistent with the experience for similar geothermal projects and have been tailored specifically to development in Hawaii.

SECTION 3. RESOURCE SUPPLY CURVES

The Resource Supply Curve (RSC) computer model is an evaluation tool for use in comparing different energy generation options on each island and within the state. The model's database currently includes cost and performance information for over 230 potential renewable energy projects. In order to account for the optimistic, nominal, and conservative estimates, the database contains over 700 entries. The information in the database is used by the RSC program to calculate levelized cost of energy estimates in 1995 dollars for potential projects based on a set of criteria and economic assumptions selected by the user. Guidelines for using the model are included in Appendix A.

The model searches the database based on the chosen set of parameters and provides a graphical and tabular summary of the results of the query. The user can chose particular islands (or all islands), specific technologies (or all technologies), technology stage (current, future, or both), transmission cost (include, exclude, or both), certainty level (optimistic, nominal, conservative, or all), and project size ranges. The model is extremely flexible in that projects can be added or edited, and the majority of the economic parameters can be changed to represent different circumstances.

ECONOMIC ASSUMPTIONS

As previously discussed, the RSC model calculates levelized cost of energy in 1995 dollars based on the EPRI TAG methodology. The user has a choice of evaluating projects based on two valuation methods and two basic financing options. The valuation methods include constant dollar analysis (no inflation) or current dollar analysis. Financing options include either utility or non-utility financing. Default values are provided for each choice. For the utility financing options, the default values are those reported by HECO and HELCO in their Integrated Resource Plan submittals to the Hawaii Public Utility Commission. For non-utility financing, the default values are based on experience in obtaining financing for recent renewable energy independent power projects. To maximize the flexibility of the program, the user has the further option of changing the debt/equity ratios, the tax life, the inflation rate, the debt cost, the equity cost, the property tax, and the state and federal income tax to values other than the default values.

The cost of energy analysis also considers both state and federal tax credits and incentives. For each technology, both investment tax credits and production tax credits are included. The program assumes that the full value of the tax credits can be utilized. The user has the option of changing the default values or turning off the tax credits completely. A summary of the default settings for the economic variables is shown in Table 1.

RENEWABLE ENERGY PROJECTS INCLUDED IN THE DATABASE

Tables 2 through 5 list the potential renewable energy projects that are included in the database for each island. Additional information on the screening process to identify project sites and the characteristics of each project site are included in the Phase 1 report, *Renewable Energy Resource Assessment Plan*. Although no project sites are included in the database for either Lanai or Molokai, renewable energy has potential on these islands for use in small-scale applications. On these islands, the size of the utility grid, the extent of the existing renewable energy projects, and the projections for demand growth limit consideration of any additional utility-scale renewable energy projects at this time.

It should be noted that the list of projects included in the database is slightly different than those included in the Phase 1 report. In developing cost and project size estimates, several projects no longer appeared viable compared to other alternatives. In particular, several of the biomass projects were combined into larger projects and only representative combinations of crop types and project sites were evaluated to limit the size of the database. Other combinations may be viable. In addition, a few of the smaller hydroelectric projects were eliminated. A number of specific wave energy projects on each island have also been added to the database.

ILLUSTRATIVE RESOURCE SUPPLY CURVE RESULTS

Illustrative results from the resource supply curve program based on one possible set of economic parameters are shown in Appendix B. In the examples, only the most cost-effective project size is shown for each project site. An example is provided by island for all technologies (showing the most cost-effective projects at each project site on that island) and by technology for all islands (showing the most cost-effective projects at each project site within the state).

The illustrative results show that biomass projects using organic waste as a fuel source and wind energy projects are the least expensive options on each island. The biomass results are strongly dependent on the revenue that can be obtained from the tipping fees collected for waste disposal. Wind energy projects on each island are one of the lowest cost renewable energy alternatives under both current and future technology scenarios. Although only two hydroelectric projects were identified with significant development potential, current hydroelectric technology also offers one of the least-cost renewable energy options. For the technologies under development, cost and performance improvements in the future result in significantly lower cost-of-energy estimates in the future scenarios.

Appendix C includes the technology data worksheets with the supporting documentation for the cost and performance estimates. A separate worksheet showing optimistic, nominal, and conservative estimates is included for each project size and technology stage for all identified potential renewable energy projects. Each technology data sheet contains itemized cost and performance estimates that show the cost and performance assumptions that were applied in this study.

Table 1. Resource Supply Curves Variable Summary

Program Settings and Options: 28-Sep-95

Financing Option:	Utility		**Valuation Option:**	Constant Dollars
Financing Variables	Utility	Non-Utility	**Valuation Variables**	
Debt Ratio	45%	70%	**Current Dollar:**	
Equity Ratio	55%	30%	Inflation	4.10%
Debt Interest Rate	7.5%	9.0%	Discount Rate	10.14%
Equity Return Rate	12.3%	18.0%	**Constant Dollar:**	
			Inflation	N/A
			Discount Rate	5.8%

Table 2. Hawaii Projects

Technology	Project Location	Size (MW)
Wind	Kahua Ranch	5, 15
	Lalamilo Wells	3, 30, 50
	N. Kohala	5, 15
Solar Thermal		
Dishes	Keahole	30
	N. Kohala	5, 15
	Waikoloa	30
Trough	Keahole	30
	Waikoloa	30
Photovoltaic		
Fixed	Keahole	30, 50
	N. Kohala	5, 15
	Waikoloa	30, 50
Tracking	Keahole	30, 50
	N. Kohala	5, 15
	Waikoloa	30, 50
Geothermal	Kilauea	25, 50
Biomass Electric		
Grass Crops	Hamakua Coast	25
	Hilo Coast	25
	Ka'u	25
Tree & Organic Waste	Hilo Coast	50
Tree Crops	Hamakua Coast	25
	Hilo Coast	25
Biomass Fuel-Methanol		
Grass Crops	Kaumakai	25 MGPY
Tree Crops	Hamakua Coast	25 MGPY
	Hilo Coast	25 MGPY
Hydro	Umauma Stream	13.8
Wave	Honokaa	10
	N. Kohala	10, 30
	Pepeekeo	10
Ocean Thermal	Keahole Point	60

Note: Project size is given in MW of installed capacity except biomass-fuels, which are given in millions of gallons per year.

Table 3. Maui Projects

Technology	Project Location	Size (MW)
Wind	McGregor Point	30
	N.W. Haleakala	10, 30, 50
	Puunene	10, 30
	West Maui	10, 30, 50
Solar Thermal		
Dishes	Kahului	10, 30
	Kihei	10, 30
	Puunene	10, 30
Trough	Kahului	30
	Kihei	30
	Puunene	30
Photovoltaic		
Fixed	Kahului	10, 30
	Kihei	10, 30
	Puunene	10, 30
Tracking	Kahului	10, 30
	Kihei	10, 30
	Puunene	10, 30
Biomass Electric		
Organic Waste	Paia-Puunene	25
Grass Crops	Paia-Puunene	25, 50
Tree Crops	Paia-Puunene	50
Biomass Fuel-Ethanol		
Grass Crops	Paia-Puunene	25, 50 MGPY
Tree Crops	Paia-Puunene	25 MGPY
Biomass Fuel-Methanol		
Organic Waste	Paia-Puunene	25 MGPY
Grass Crops	Paia-Puunene	50 MGPY
Tree Crops	Paia-Puunene	50 MGPY
Wave	Lower Paia	10, 30, 60
	Opana Point	10, 30, 60
	Waiehu Point	10, 30

Note: Project size is given in MW of installed capacity except biomass-fuels, which are given in millions of gallons per year.

Table 4. Oahu Projects

Technology	Project Location	Size (MW)
Wind	Kaena Point	2, 15
	Kahuku	30, 50, 80
Solar Thermal		
Dishes	Lualualei	50
	N. Ewa Plain	50
	Pearl Harbor	50
Trough	Lualualei	80
	N. Ewa Plain	80
	Pearl Harbor	80
Photovoltaic		
Fixed	Lualualei	10, 20, 50
	N. Ewa Plain	10, 50
	Pearl Harbor	10, 50
Tracking	Lualualei	10, 20, 50
	N. Ewa Plain	10, 50
	Pearl Harbor	10, 50
Biomass Electric		
Organic Waste	Barber's Point	50
Grass Crops	Waialua	25
Biomass Fuel		
Organic Waste-Ethanol	Barber's Point	25 MGPY
Organic Waste-Methanol	Barber's Point	50 MGPY
Wave	Makapuu	30, 60
	Mokapu Point	30
	N.E. Coast (upper)	30
	N.E. Coast (lower)	30
	Waimanalo	30
	Kahuku Point	30, 60
Ocean Thermal	Kahe Point	60

Note: Project size is given in MW of installed capacity except biomass-fuels, which are given in millions of gallons per year.

Table 5. Kauai Projects

Technology	Project Location	Size (MW)
Wind	Anahola	7
	N. Hanapepe	10
	Port Allen	5
Solar Thermal		
Dishes	Barking Sands	10
Photovoltaic		
Fixed	Barking Sands	10
Tracking	Barking Sands	10
Biomass Electric		
Grass Crops	Kaumakani	25
	Lihue	25
Tree & Organic Waste	Kaumakani	50
Tree Crops	Kaumakani	25
	Lihue	25
Biomass Fuel-Methanol		
Tree Crops	Kaumakani	25 MGPY
	Lihue	25 MGPY
Hydro	Wailua River	6.6
Wave	Anahola	10, 30
	Barking Sands	10, 30

Note: Project size is given in MW of installed capacity except biomass-fuels, which are given in millions of gallons per year.

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APPENDIX A

GUIDELINES FOR USING THE RSC COMPUTER MODEL

RSC program assistance will be provided at no cost for a period of one year. For assistance please contact Rana Vilhauer at RLA Consulting. Assistance is available by calling 206/488-0848 Monday through Friday from 8 AM to 4 PM (PST) or by fax by 206/488-0977. For additional assistance call DBED&T, Energy Division at 808/587-3800.

Hawaiian Renewable Energy Resource Supply Curve (RSC) Computer Model

INTRODUCTION

The purpose of the Resource Supply Curve (RSC) model is to provide the Department of Business, Economic Development & Tourism (DBED&T) with an evaluation tool for incorporating renewable energy into Hawaii's energy mix.

The RSC model was developed by R. Lynette & Associates, Inc. (RLA) under the Renewable Energy Assessment portion of the Hawaii Energy Strategy Program. RLA and affiliated subcontractors developed the database of potential renewable energy projects which is the foundation of the RSC model.

The results of the program are a graphical presentation of the cost of energy of each project versus the cumulative energy for all the projects meeting a specified criteria. Figure 1 is a sample of the graphical presentation and tabular summary which shows the potential projects that match a set of criteria selected by the user.

Following is a description of the menu-driven RSC model, the basis of the model, and its intended use. The RSC model and the economic assumptions is incorporates are based on the EPRI TAG methodology for calculating the levelized cost of energy for potential projects.

REQUIREMENTS

The model is intended to be used by DBED&T in its analysis of potential renewable energy projects in the State of Hawaii. The model is to be operated in QPro for Windows Version 5.0. The model was written on a 486 DX with 16 MB of RAM. Although the RSC model will run on a 386 computer, a 486 with at least 8 MB of RAM is recommended. The computer operator will be more comfortable with the model if they have some experience with Windows-based programs. The program is intended to be operated to a large degree with the use of a mouse.

INSTALLATION AND OPERATION

The RSC Model is a Quattro Pro for Windows file that makes use of Quattro Pro's spreadsheet, database, macro, and custom application capabilities. The model is executed by opening the file RSC_Ver4.WB1. The model is operated by selecting menu choices and dialogue box options. The main menu headings are RSC, variables, add, edit/delete, print/view, and quit. The following sections describe the operations available under each menu heading.

RSC

Choose this option to develop curves from the database of potential projects.

The RSC menu choice brings up a three-item secondary menu. The RSC process is begun by choosing to perform a New Query or going back to the Previous Query settings. You also have the option to Quit the program at this secondary menu level.

New Query

New Query provides the user choices of island, technology, technology stage, transmission cost, certainty level, and project size boundaries. These are the parameters by which the program will search the database.

Figure 1

Figure 2 shows the Project Study dialog box which is displayed on the screen when the user chooses "New Query." The use has the following options for defining the data query criteria.

- *Island* - one island, all islands, or combination of islands can be included.

- *Technology* - one, all, or any combination of the technologies may be included.

- *Technology Stage* - current, future, or a comparison of both (two lines are shown on the RSC graph).

- *Transmission Costs* - costs included in COE, excluded, or a comparison of both (two lines are shown on the RSC graph).

- *Certainty Level* - optimistic, nominal, conservative, or a comparison of all levels (three lines are shown on the RSC graph).

- *Installed Capacity* - any range of project size is allowed within the default setting of 0-999 MW.

Figure 2

Graphing multiple comparisons within a single graph produces results that tend to be unclear. Multiple comparisons have been avoided by incorporating exclusions within the Project Study dialog box. For criteria settings for Technology Stage, Transmission Costs, and Certainty Level, if a multiple comparison has been chosen for one setting, multiple comparisons are excluded for the other two. For example, if the user chooses Both under Technology Stage, the options for Transmission Cost Comparison and All Levels of Certainty are “grayed” by the program and cannot be chosen.

when the user has defined the set of criteria and clicked on OK, the program will search the database to find records that meet the selected criteria.

The user is then prompted with a **Graphing Choice** to provide further search refinement. As shown in Figure 3, this prompt offers three possibilities.

- *Option 1* - Graph all projects found in the query.

- *Option 2* - Graph only the project with the lowest COE for each unique location (a single project is chosen for each location based on lowest COE). This option results in a short waiting period while the program sorts and eliminates extraneous data.

- *Option 3* - Allow for manually choosing the projects to graph from the data found in the query. This option allows the user to review the projects that met the criteria and manually eliminate unwanted projects.

Figure 3

After the graphing choice is made, there is a waiting period and then the **Benchmarks** prompt is given. This prompt provides the option to include a benchmark COE value as a graphical comparison to the projects selected by the user's criteria settings. The benchmark is shown on the RSC graph as a single vertical line. Figure 4 shows the currently available benchmark options.

After the benchmark choice has been made, there is a short wait as the program processes the data. The length of the waiting period depends on the computer speed and the number of database records that met the search criteria. For example, choosing All Islands will require a longer waiting period than choosing only one island. The program is still processing if a "wait" or "macro" indicator appears in the lower right corner of the screen. When the calculations have been performed, the graph

Figure 4

has been setup, and the data table assembled, the user will be prompted to choose between printing or viewing the results. The default setting is View. If the user chooses to view, they can later choose to print the current RSC graph and related data table from the main menu.

Previous Query

Previous Query begins with the criteria settings from the last query performed. This is useful for refining your criteria choices or performing similar queries. In all other ways, Previous Query provides the same choices and produces the same results as New Query.

Quit

Quit provides the opportunity to save (or not save) your changes, return QPro to its default settings, and exit the program.

VARIABLES

Choose this option to view or change the economic assumptions used in developing curves.

The Variables menu choice brings a four-item secondary menu that allows for changing, viewing and printing and current economic parameters, settings used in the program.

Choosing Calculation Method

User chooses the Valuation Method, either Constant or Current Dollar analysis; the Financing Option, either Utility or Non-Utility; and Tax Credits, either Included or Excluded. The discount rate, inflation rate, and debt equity ratio associated with these choices are shown. The dialog box, which is presented as Figure 5, also provides the user with a view of the current Economic Assumptions and Tax Credit settings.

Figure 5

Change Economic Assumptions

The Economic Assumptions may be updated periodically, including the Financing Ratios and Tax Credits values, in the dialog box which is represented as Figure 6. It is advisable to have one person who is responsible for making required changes. Therefore, this option is password protected (Password = DBED). When leaving this dialog box with an **OK**, a macro is initiated that recalculates the Fixed Charge Rate tables.

Change COE Benchmarks

This option allows for updating the list of benchmarks and their related values. The Benchmarks dialog box with its current settings was shown previously in Figure 4.

Print Variables Summary

This option will send a summary of the variable settings to the printer.

ADD

Choose this option to add records to the database.

This option brings up the data entry form, shown in Figure 7, for entering new projects into the existing database. Information in the database was entered based on the Technology Data Sheets provided in Appendix C as documentation for the program. The Add Record entry form provides

Figure 6

Figure 7

"pick lists" for several entry fields, which ensures that only acceptable field entry choices can be made. For example, there is a pick list for Technology which provides a list of all technology options currently available in the program. The user must choose one from the list.

Users are informed that the program requires project data records in multiples of three; Optimistic, Nominal and Conservative certainty levels. In most cases the user will also be entering project data records for Current and Future technology stages. It is recommended that a Technology Data Sheet be completed prior to adding a new project to the database. The data sheet can then be used to facilitate the addition of the record to the database.

EDIT/DELETE

Choose this option to edit or delete existing records in the database.

Editing and deleting data is accomplished by the use of a QPro Data Form, shown in Figure 8. This form is very flexible. Specific records can be easily found by using the Search option. Unwanted records can be permanently deleted from the database. It is, however, also very easy to accidentally make changes to the database in this form. Therefore, this option is password protected (password = DBED).

PRINT/VIEW

Choosing Print/View allows the user to view or print the most recently generated RSC graph and related data table.

QUIT

Quit provides the opportunity to save (or not save) your changes, return QPro to its default settings, and exit the program.

Figure 8

APPENDIX B

ILLUSTRATIVE RESULTS FROM THE RSC COMPUTER MODEL

APPENDIX C

TECHNOLOGY DATA SHEETS